Studies of isolated photon production in simulated proton-proton collisions with ALICE-EMCal

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Abstract. The production of prompt photons at high transverse momentum in proton-proton collisions (p-p) is a useful tool to study perturbative Quantum-Chromo-Dynamics (pQCD). In particular, they yield valuable information about parton distribution functions in the proton. The experimental measurement of prompt γ is a difficult task due to the large background of decay photons from neutral mesons, mainly π^0. We present a full simulation and reconstruction study of prompt γ identification in p-p at $\sqrt{s}$ = 14 TeV in the ALICE electromagnetic calorimeter EMCal, giving details on the methods developed to separate them from decay photons with the help of shower-shape and isolation cuts. We present Monte Carlo predictions for signal and background. The method used to extract the final isolated γ corrected cross-section is presented and the calculation of various experimental corrections is outlined.

1. Physics motivations

The study of photon production at large transverse momenta ($p_T \gg \Lambda_{QCD} = 0.2$ GeV) in hadronic interactions is a valuable testing ground of the perturbative regime of Quantum Chromodynamics (pQCD) [1]. At the LHC, photons will allow one to confront the data with pQCD predictions at energies never reached before. Since these photons come directly from parton-parton hard scatterings, they allow one to constrain the gluon distribution function in the proton at small parton momentum fraction $x = p_{parton}/p_{proton}$. Also, photons produced in p-p collisions provide a vacuum baseline reference for the study of their production rates in nucleus-nucleus collisions.

At lowest order, three partonic mechanisms produce prompt γ in hadronic collisions: (i) quark-gluon Compton scattering $qg \to \gamma q$, (ii) quark-antiquark annihilation $q\bar{q} \to \gamma g$, and (iii) the collinear fragmentation of a final-state parton into a photon, e.g. $qq \to qq \to \gamma X$. The photons produced in the two first point-like processes are called *direct*, the latter *fragmentation* photons. The Compton channel is particularly interesting as it provides information on the proton gluon distribution [2], which is otherwise only indirectly constrained via the "scaling violations" of the proton structure function in deep-inelastic scattering (DIS) e-p collisions [3].

The measurement of high-p_T photon production is complicated by a large γ background from hadrons, specially from π^0 mesons, which decay into two photons. At high p_T there are between 10 and 100 (at 100 GeV/c and 10 GeV/c respectively) times more π^0 than prompt γ. Furthermore, above 30 GeV/c, the two π^0 decay photons merge into a single cluster in EMCal and thus cannot be identified as a π^0 via γ-γ invariant mass analysis. In order to measure the prompt γ signal out of the overwhelming background of π^0, which are produced in

the fragmentation of jets, one requires the photon candidate to be isolated from any hadronic activity within a given distance around its direction. The corresponding measurements are then dubbed *isolated* photons. A standard isolation requirement is that within a cone around the γ direction defined in pseudo-rapidity η and azimuthal angle ϕ by $R = \sqrt{(\eta - \eta_\gamma)^2 + (\phi - \phi_\gamma)^2}$, the accompanying hadronic transverse energy is less than a fixed fraction ε (e.g. often 10%) of the photon's p_T. R is usually taken between 0.4 and 0.7. Isolation enables one to reject a large fraction of the π^0 decay photons, without supressing too many photons of interest. The bigger R and the smaller ε, the more selective is the isolation. But the choice of optimal isolation criteria also needs to consider detector acceptance and Underlying Event (UE) limitations. The values choosen are $R = 0.2$ (for the first year of running at $\sqrt{s} = 7$ TeV, with only 4 Super-Modules of EMCal installed), $R = 0.4$ and $\varepsilon = 0.1$ (which e.g. removes UE-hadrons with p_T <2 GeV/c in events with a 20-GeV γ).

2. Monte Carlo predictions

The `JETPHOX` [4] program (for JET-PHOton/hadron X-sections) allows one to calculate perturbatively the γ cross-sections at Next to Leading Order accuracy. It includes both the fragmentation and the direct components and isolation cuts can be applied at the parton level. Figure 1 shows the expected isolated photons (R =0.2, ϵ=0.1) cross-sections at 7 TeV

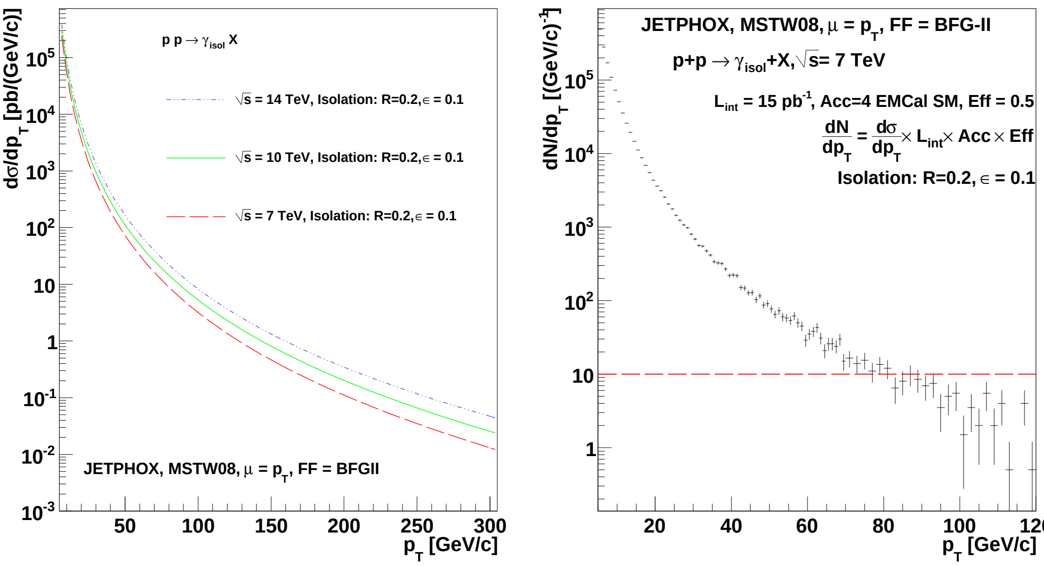

Figure 1. Differential cross-section as a function of p_T for isolated photons (R =0.2, ϵ=0.1) in p-p collisions at $\sqrt{s} = 7$, 10 and 14 TeV (left) in one unit of rapidity at mid-rapidity and expected isolated yields and p_T reach at $\sqrt{s} = 7$ TeV, for an integrated luminosity of L = 15 pb^{-1} (right).

and, for comparison, at 10 and 14 TeV (left) and the corresponding yields in p-p at 7 TeV (right). The expected p_T reach, which will be accessible in the ALICE EMCAL acceptance ($\Delta\eta = 1.4, \Delta\phi$=1.1), during the first year of LHC running at $\sqrt{s} = 7$ TeV, considering an integrated luminosity[1] of L = 15 pb^{-1}, is found to be around 80 GeV/c. `PYTHIA 6.420` [5], with the Perugia hard and soft tunes [6], has been used to study the signal and the background, for p-p collisions at $\sqrt{s} = 14$ TeV. We have generated the different photon subprocesses: Compton

[1] We assume fully-efficient high-p_T EMCal cluster triggers with no scale-down reduction.

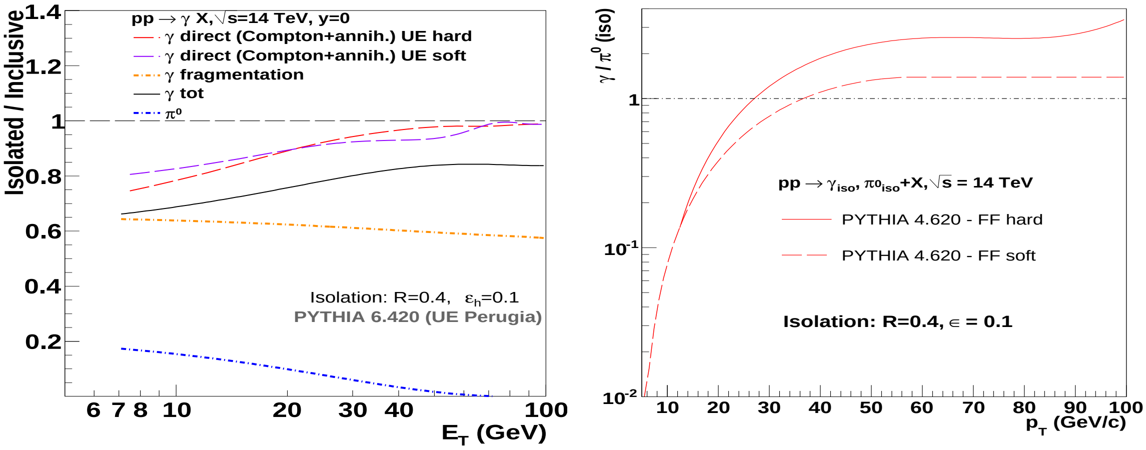

Figure 2. Fraction of isolated ($R = 0.4$, $\varepsilon = 0.1$) over inclusive photons and π^0 for p-p collisions simulated by PYTHIA at $\sqrt{s}$ =14 TeV (left), and signal (γ) over background (π^0) after isolation cuts for both the FF hard and soft PYTHIA tunes (right).

(MSUB = 29), annihilation (MSUB = 14) and fragmentation (MSEL = 14), as well as π^0 (MSEL = 1) events, over one unit of rapidity at $y = 0$, for different p_T bins: [5-20], [20-50], [50-100], [100-250], [250-500] and [500-1000] GeV/c, with 10 millions events in each. Isolation cuts ($R = 0.4$, $\varepsilon = 0.1$) have been applied on them. Figure 2 (left) shows the fraction of isolated over inclusive particles, for the different photon subprocesses and for π^0, at the MC level. For the direct γ, which are theoretically all isolated, we have studied the effect of the UE on the isolation by using two different PYTHIA tunes, hard and soft, which differ by their proportions of initial and final-state radiation, multiple interactions, beam remnants and parton-to-hadron fragmentation functions (FF). The fraction of isolated direct photons ($R = 0.4$, $\varepsilon = 0.1$) goes from 80% to 100% from 10 to 100 GeV. Thus, the UE leads to a maximum of 20% (±5%) of isolated direct photons loss at 10 GeV. The fraction of isolated fragmentation photons with PYTHIA is around 60%. This leads to a total amount of isolated over inclusive γ of about 70-80% over the full E_T range. The isolated π^0 fraction is represented by high-z π^0 which carry a large fraction of the jet energy ($z = p_{hadron}/p_{parton}$) and are thus isolated from accompanying hadronic activity. With PYTHIA we find a fraction of isolated π^0 going from 20% to 3% from 10 GeV to 60 GeV. High-z isolated π^0 are thus considered as the main background in our prompt isolated photon analysis.

Figure 2 (right) shows the MC-level predictions for the signal over background (S/B) with isolation cuts, for both PYTHIA tunes, in order to assess the systematic uncertainty linked to the choice of the FF. Isolation allows one to strongly enhance the signal over background ratio. Yet, with isolation cuts, the S/B remains smaller than 1 up to $\sim$ 30 GeV/c. In order to suppress the remaining background due to isolated π^0, one thus needs to employ shower-shape cuts which improve the photon over π^0 ratio, and subtract statistically any final remaining π^0 background.

3. Analysis

The goal of this analysis is to obtain a fully corrected isolated prompt photon spectrum at 14 TeV. The isolated photon cross-section can be written as :

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{2\pi p_T}\frac{1}{p(\gamma|\gamma)}\left(\frac{\mathrm{N(clusters\ iso.\ et\ id.}\ \gamma)}{A \times L \times \epsilon \times \Delta p_T \times \Delta\eta} - p(\gamma|\pi^0)\frac{d\sigma^{\pi^0_{iso}}}{dp_T}\right) \tag{1}$$

with N(clusters id. γ and iso.) the number of clusters identified as photons and isolated, which represents the Signal+Background, p($\gamma|\gamma$) the gamma identification efficiency [2] and p($\gamma|\pi^0$) the identification contamination due to π^0 identified as photon, L the integrated luminosity, A the acceptance term, and ε all the other corrections (reconstruction and UE isolation, shown in Fig. 2 left). For the acceptance term, we consider a fiducial cut corresponding to an isolation radius of $R = 0.4$, which represents 1/4 of EMCal acceptance. The acceptance with respect to full coverage for one unit of rapidity at mid-rapidity is thus found to be around 10%. Full simulation and reconstruction events for signal (γ-jet) and background (di-jets) at 14 TeV have been used to obtain all correction factors in Eq. (1). The clusters are identified by the shower shape

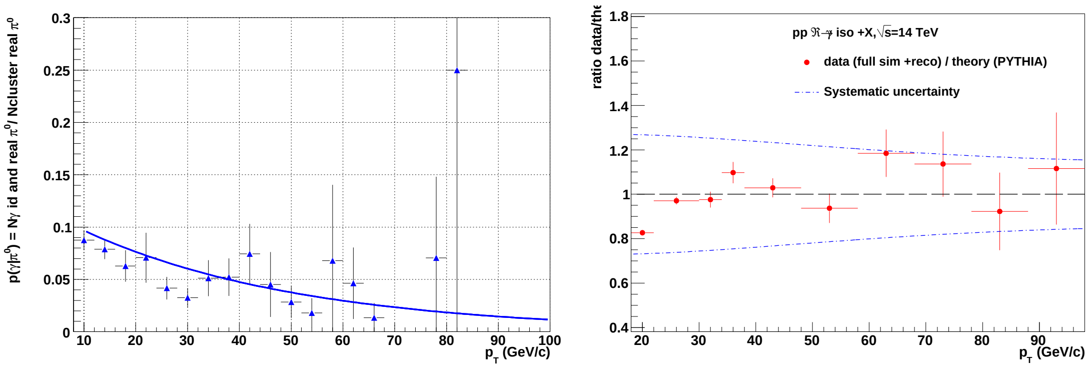

Figure 3. PID contamination of the π^0 identified as γ, p($\gamma|\pi^0$) (left), and ratio data/theory (full sim reco vs PYTHIA) for isolated γ ($R = 0.4$, $\varepsilon = 0.1$) in p-p at $\sqrt{s}$ =14 TeV (right).

Bayesian method [7]. A track-matching cluster–charged particle cut, using information from the central tracker, is also applied on the photon candidates. The photon identification efficiency, $p(\gamma|\gamma)$, is found to be constant at $\sim$80% up to 45 GeV/c. The background contamination due to π^0's identified as γ, $p(\gamma|\pi^0)$, is found to be less than 10% above 10 GeV/c and decreasing with p_T (Fig. 3 left). Our shower-shape cuts remove, thus, a significant fraction of neutral pions. The reconstruction efficiency is $\sim$90% up to $\sim$80 GeV/c. The signal/background after photon reconstruction, identification and isolation is found to be greater than one above $p_T \approx 15$ GeV/c.

Finally, we use the `PYTHIA` spectrum of isolated π^0 to statistically remove any remaining contamination. This π^0 cross-section, weighted by the term $p(\gamma|\pi^0)$, is subtracted from the fully-corrected left term of Eq. (1) to obtain the final corrected isolated γ spectrum at 14 TeV. The systematic errors propagated on the final yields are dominated by the EMCal energy scale (about 15%) and the (theoretical) uncertainty in the subtracted isolated-π^0's ($\sim$20%). Fig. 3 (right) shows the final data/theory ratio, i.e. the ratio of the full sim+reco spectrum over the original `PYTHIA` distribution. The fully corrected spectrum is in good agreement with the input MC LO spectrum within the expected statistical (for 24 pb^{-1}) and systematic uncertainties.

References

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[2] Defined as a conditionnal probability of identifying a reconstructed cluster as a γ knowing that it is indeed a γ.